WEAR RESISTANCE OF Al-Si ALLOYS

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ABSTRACT

The wear behavior of Al-Si alloys and the influence of dispersed Si particles on the wear resistance of the alloys were investigated in the present study. Two kinds of Al-Si alloys (Al-12.5%Si and Al-25%Si) were used for the experiments. Test specimens cut from the ingots of the alloys were heat treated at temperatures from 450 to 565 ℃ for various periods to change the state of distribution of dispersed Si particles. The wear resistance of the alloys was tested with a wear testing machine. The hardness of the heat treated alloys were measured. Furthermore, the microstructures of the alloys were observed and the size distribution of Si particles were determined.

The wear resistance of Al-25%Si alloy is higher than that of Al-12.5% Si alloy, because of larger volume fraction of Si phase. For the constant Si content, the wear resistance of the alloys increased with the number of Si particles. The number of Si particles in the alloys increased by heating at high temperatures. The wear resistance of SiC alloys is mainly dependent on the distribution state of the dispersed Si particles rather than the hardness of the matrix.

Keywords: *wear resistance, Al-Si alloy, eutectic matrix, crystallized particle, heat treatment*

1. INTRODUCTION

Wear of machine parts is a big problem in industrial uses. Recently, the applications of aluminum alloys for the machine parts are increasing. However, little has been reported on the wear behavior of aluminum alloys. The wear resistance of alloys may depend on the hardness of the matrix and the dispersed second phase particles in the alloys. In the Al-Si binary system, the solubility of Si in Al is very small and the solubility of Al in Si is null and there is an eutectic point between the two elements [1] . Al-Si alloys are composed of a matrix with the composition of eutectic Al-Si and particles of crystallized Si. The distribution state of Si particles in the alloys can be changed by heat treating. Therefore, Al-Si alloys are suitable for studying the effect of second phase particles on the mechanical properties of the alloys. In the present study, the wear behavior of Al-Si alloys was investigated. The influence of dispersed second phase particles on the wear resistance of Al-Si alloys was also studied with changing the distribution state of the crystallized particles by heat treating the alloys.

2. EXPERIMENTAL

Commercial Al-Si alloys with the compositions of 12.5%Si and 25%Si were used as the starting material. The alloys were remelted and cast into small ingots in the laboratory, because Si was significantly segregated in the commercial ingots. The new ingots were heated at 350 ℃ for 25 h to homogenize the structures. The specimens for testing wear resistance, hardness and microstructure were cut from the ingots and heat treated at various temperatures from 450 to 560 ℃ to change the distribution state of Si particles in the alloys. The conditions of heat treatments are shown in Table 1. The conditions of heat treatments will be referred by numbers in Table 1 hereafter. The hardness representing the whole body of the alloy was measured with the Rockwell B scale (HRB) and the hardness of the matrix and Si particles was measured with the micro Vickers hardness (load:200gf) (HV0.2). The specimens for metallography were polished and etched and the microstructures of the alloys were observed with an optical and an electron microscopes, and the mean size and the number of Si particles per unit area were determined. The wear resistance of the alloys was tested with an Oogoshi type wear testing machine, in which a flat specimen was pressed against a metal disk rotating at constant speed. The wear of the alloys was measured by the width of a scar on a specimen. The principle of the wear testing machine is shown in Fig.1. The disk with a diameter of 30mm and the width of 3mm is made of steel (S45C) and rotated at 400 rpm. In this testing method, the wear resistance is represented as a wear coefficient which is the volume loss per abraded distance and load added on the disk. The unit of the wear coefficient becomes (mm^2/N) or (mm^2/kgf). Thus, the smaller value of wear coefficient, the better wear resistance.

Table 1 Conditions of heat treatments.

	Temperature		Time
1.	450 ℃	x	1 h
2.	520	x	5
3.	520	x	10
4.	550	x	10
5.	560	x	10

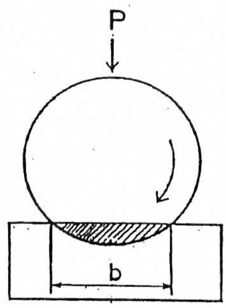

Fig.1 Principle of wear testing machine (Oogoshi type). (b: Width of a scar.)

3. RESULTS

The change in wear coefficient of Al-25%Si alloy with the conditions of heat treatment is shown in Fig.2. The conditions of heat treatment will be represented by numbers in Table 1 hereafter in figures. The increase of the number corresponds to the increase in temperature and time of heat treatment. The wear coefficient of Al-25%Si alloy decreases, that is, the wear resistance increases with increasing temperature and time of heat treatment. The changes in the hardness of Si particle, matrix and whole body in Al-25%Si alloy are shown in Fig.3. The hardness of Si particle and matrix is represented with the micro Vickers scale (HV0.2) and the hardness of whole body is represented with the Rockwell B scale (HRB) in this figure. The hardness of Si particle does not change so much, but the hardness of the matrix rather decreases with the conditions of heat treatment. The change in the hardness of whole body with the

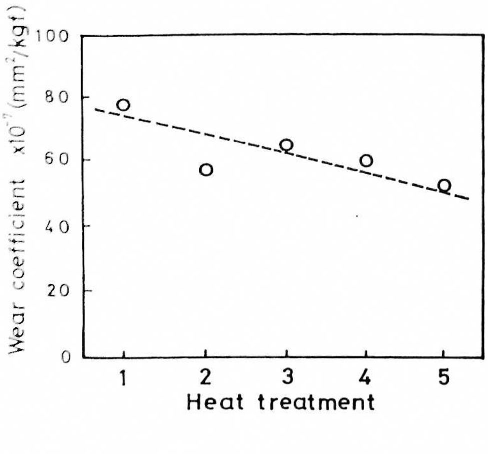

Fig.2 Change in wear resistance with conditions of heat treatments. (Al-25%Si alloy)

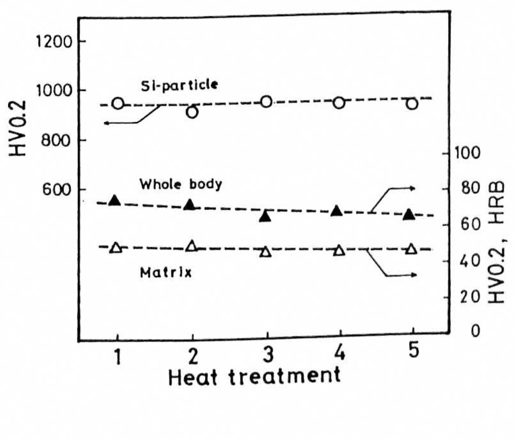

Fig.3 Change in hardness of Matrix, Si particle and whole body with conditions of heat treatments. (Al-25%Si alloy)

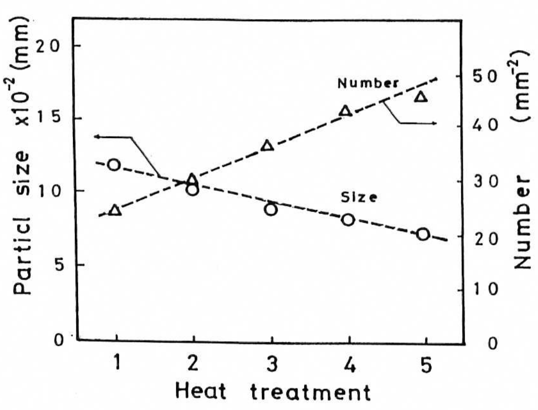

Fig.4 Change in particle size and number of Si crystals with conditions of heat treatments. (Al-25%Si alloy)

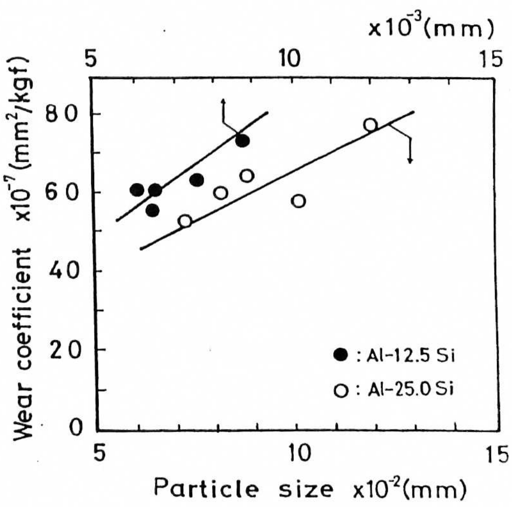

Fig.5 Relations between wear resistance and particle size in Al-Si alloys. (Al-25%Si, Al-12.5%Si alloys)

conditions of heat treatment is similar to that in the hardness of matrix. This means that the hardness of whole body rather represents the hardness of the matrix than that of Si particles. These changes in Fig.2 and 3 show that the wear resistance of Al-Si alloy mainly depends on the state of distribution of crystallized Si particles in the alloy, not on the hardness of matrix. The changes in the mean size and the number per unit area of Si particles in Al-25%Si alloy is shown in Fig.4. The mean size of Si particles decreases, but the number of Si particles per unit area increases with increasing temperature and time of heat treatment. It means that Si particles in Al-Si alloy become smaller, but increase the number during heat treatment, suggesting that large primary crystallized Si particles are divided into smaller particles by the heat treatment. Finally, the wear coefficient was plotted against the mean diameter of Si particles in Fig.5. The data of Al-12.5%Si alloy are plotted together with the data of Al-25%Si alloy in this figure. The wear coefficient increases with increasing the mean diameter of Si particles in Al-Si alloys. It can be said from this figure that the wear resistance of Al-Si alloys increases with decreasing the mean diameter of Si particles in the alloys.

4. DISCUSSION

The wear resistance of alloys with dispersed second phase particles may depend on the hardness of matrix and dispersed particles in the alloys. In the Al-Si binary system, there is an eutectic point between the constituent elements; Al and Si, and the solubility of Si in Al is very small and the solubility of Al in Si is almost null [1] . On the solidification of Al-Si alloys, Si crystallizes as the primary crystals at first and then, the eutectic matrix fills up the space between Si particles. Therefore, Al-Si alloys are composed of an eutectic matrix and primarily crystallized dispersed Si particles. An example of microstructure of the alloy is shown in a micrograph in Fig.6. It has been reported that the wear resistance of Al base alloys without a second phase increases with the hardness of matrix [2] . The purpose of this study is to reveal the effect of the dispersed second phase particles on the wear resistance.

As shown in Fig.3, the hardness of Si particles does not change, but the hardness of matrix changes by heat treatment. The hardness of matrix as well as the hardness of whole body of the alloy decreases with increasing temperature and time of heat treatment. However, the wear coefficient of the alloy decreases inversely with increasing temperature and time of heat treatment as in Fig.2. The hardness of whole body may be the hardness of matrix without including the effect of Si particles. If the hardness representing the wider area, such as the Brinell hardness, were used, the trace of indent would include many Si particles and the hardness of whole body would reflect the effect of dispersed phase. As the solubility of Si in Al increases a little at high temperatures, Si in Si particles will diffuse into Al grains in the eutectic matrix of Al-Si alloy when temperature is raised. Consequently, Si particles in the eutectic matrix will become smaller causing to the softening of matrix with increasing temperature and time of heat treatment. However, the hardness of Si particles is much higher than that of matrix, so that, the wear resistance of the alloys depends only on the hardness of Si particles, unconcerned with the hardness of matrix.

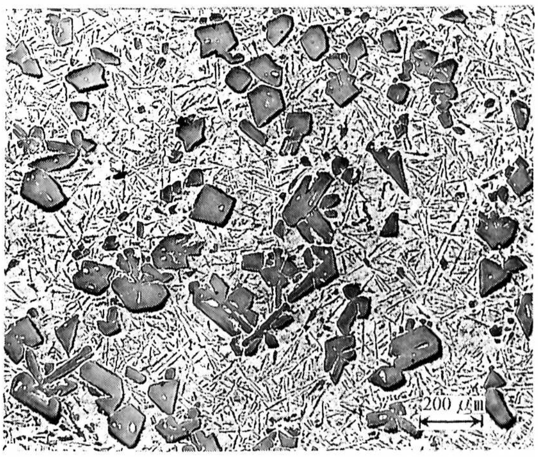

Fig.6 Microphotograph of Al-25%Si Alloy.

On the other hand, the mean diameter of Si particles decreases, but the number of the particles increases with increasing temperature and time of heat treatment as shown in Fig.4. This means that the Si particles are divided into smaller particles increasing the number of particles resulting in the better wear resistance with increasing temperature and time of heat treatment as shown in Fig.2. The microstructural change that the primarily crystallized Si particles become smaller and increase number is due to the fact that the narrow parts connecting Si primary crystals dissolve into the matrix faster than the primary crystals.

As shown in Fig.5, the wear coefficients of Al-12.5%Si alloys are larger than those of Al-25%Si alloys, because the volume fraction of Si in Al-12.5%Si alloy is smaller than that of Al-25%Si alloy. The wear coefficient of Al-12.5%Si alloy decreases, that is, the wear resistance increases with decreasing the mean size of Si particles as well as in Al-25%Si alloy. The better wear resistance of Al-Si alloys may be achieved by making the alloys with uniformly dispersed smaller Si particles.

It can be concluded from the above mentioned results that the wear resistance of Al-Si alloys depends rather on the state of dispersion of Si particles than the matrix, and the better wear resistance can be achieved by uniformly dispersing smaller Si particles in the alloys.

5. CONCLUSIONS

The wear behavior and the effect of dispersed Si particles on the wear resistance of Al-Si alloys were investigated and the following conclusions were obtained.

(1) The wear resistance of Al-Si alloys depends rather on the state of dispersion of Si particles than the eutectic matrix.

(2) The better wear resistance can be achieved by dispersing smaller Si particles uniformly in the alloys.

6. REFERENCES

[1] Constitution of binary alloys 2nd ed., edited by M.Hansen and K.Anderko, McGraw-Hill, 1958, p.132.

[2] S.Kohara, M.Hoshino, Y.Hirata, Y.Niimi: Proceedings of the Conference of Japan Institute of Light Metals (1995.5), p.239.